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Hydrology and Earth System Sciences Discussions

Interactive comment on "Technical Note: Bias correcting climate model simulated daily temperature extremes with quantile mapping" *by* B. L. Thrasher et al.

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We are grateful for the thoughtful consideration of this manuscript by the two reviewers, and for their constructive comments. We have addressed all comments as noted below, with "AR:" denoting our author replies.

Reviewer 1 (RC C2182) T. Bosshard (Referee)

1 Summary This technical note investigates the performance of quantile-mapping (QM) for the biascorrection of daily minimum (Tmin) and maximum (Tmax) temperature as well as the diurnal temperature range (DTR). The bias-correction is applied to general

circulation model (GCM) data of the CMIP3 database. The study shows that i) quantile-mapping leads to physical inconsistencies (i.e. Tmin > Tmax) when applied to Tmin and Tmax directly, ii) applying QM to Tmin and DTR and inferring Tmax improves the physical consistency but deteriorates the validation performance of Tmax and iii) applying QM to Tmax and DTR and inferring Tmin has the same advantage as the approach in ii) while the validation performance of Tmin remains on a similar level as in the approach in i). As a reason for the physical inconsistencies in i), the authors speculate on a relation to the bias of the snow-albedo feedback in the GCMs.

2 General comments The topic of the technical note is clearly relevant for the scientific community as QM is frequently used to post-process climate model data. The point that QM fails to correct Tmin and Tmax in a physical consistent way is made very clearly. Also, the proposed alternative approaches are presented and evaluated very clearly. The text is well structured and well-written. While reading the text, I would have liked to know more about the reasons for the problem. The authors refer to ongoing investigations and it is understood that a technical note cannot give an in-depth analysis. However, I guess it might be interesting to the readers and users of QM to get some more information about the failures of QM. I suggest acceptance of the manuscript after some minor comments have been taken into account and I am looking forward to the full scientific paper about the topic once the in-depth analysis has been accomplished.

AR: Additional in-depth analysis has been conducted as described in response to specific comments below.

3 Specific comments Page 5517, line 18: Reference to Quintana Segui et al. (2010). When reading this reference, I expected to learn something about Tmin and Tmax in an application of the quantile-mapping. However, Quintana Segui et al. (2010) do not specifically state that the relation between Tmin and Tmax is unrealistic. They generally state that the diurnal cycles are unrealistic but they do not pin-point that to the bias-correction of Tmin and Tmax. The unrealistic diurnal cycles are probably more

related to the fact that Quintana Segui et al. (2010) use a climatological diurnal cycle to reconstruct hourly data from daily data resulting from the quantile-mapping. Please put the reference in a correct context.

AR: We had difficulty in finding past work documenting this problem. The Quintana-Segui reference, while stating that downscaled diurnal cycles were unrealistic, did not, as both reviewers note, attribute this to problems in downscaling Tmax and Tmin separately. The reference has been removed from the revised manuscript, as it does not appear to be sufficiently relevant for supporting the statement where it appeared.

Page 5519, line 15: It is not clear to me why GCM biases in the mean and variance explain physical inconsistencies in Tmin and Tmax. Please explain a bit further. I learned that QM is able to correct for biases in the mean and the variance, but not for biases in the serial correlation.

AR: This is illustrated by the inclusion of a case study in the revised manuscript. Three additional figures (Figures 2, 3, and 4 in the revised manuscript, which are also included below) present an annotated case study of how biases in the GCM, along with relatively small DTR values, can produce the Tmin>Tmax case. The revised text and figures are discussed in the Results and Discussion section, which now begins as follows:

"The results for Case 1 are shown in Figure 1. Despite the wide variability in the number of cases where Tmin>Tmax after BC of the GCM output, Figure 1 shows, for extreme high and low cases, that these tend to occur predominantly at high latitudes (and this is generally the case for all of the GCM runs used in this study). For these high latitude regions the GCMs have biases in mean and/or variability that tend to produce more occurrences of Tmin>Tmax when adjusted through BC. How this can occur is demonstrated here using a single grid cell located at latitude 57N longitude 43E (northeast of Moscow, Russia) from MRI Run 3 (Run 13 in Table 1). For the decade of the 1980s, 3653 days in total, there were 198 cases where the bias correction resulted in Tmin>Tmax, which are depicted in Figure 2. For this decade, the DTR has a mean of 8.7°C and a standard deviation of 5.2°C. For the 198 cases in Figure 2, the mean DTR is 3.4°C, standard deviation 1.8°C. A two sample t-test at α=0.05 shows the difference between these means to be statistically significant with very high confidence ($p<0.0001$), demonstrating how cases with small DTR, relative to the GCM bias, are more prone to having this issue. The method by which this occurs is illustrated for the same grid cell and run used above for one of the cases in Figure 2, corresponding to April 17, 1983. The CDF for maximum temperature is constructed as described above, using a window of ±15 days around April 17. Using the period 1961-1980 as the climatological period, 620 days are used to define the CDFs. As shown in Figure 3, the GCM underpredicts the daily Tmax value throughout the distribution. Figure 4 shows the same as Figure 3, but for Tmin, which the GCM also underestimates, but by a much wider margin than for Tmax. The quantile mapping is illustrated on Figures 3 and 4, transforming the raw GCM Tmax and Tmin of 5.3°C and 1.9°C, respectively, to bias corrected values of 6.1°C and 11.6°C, respectively, producing Tmin>Tmax and a physically impossible DTR."

Page 5519, lines 18-23: Also related to the comment above. It is unclear to me how a bias in the snow-albedo feedback leads to occurrences of Tmin>Tmax in the bias-corrected data. Could you please provide some more explanations? For me, it would be very illustrative to see a particular case where this happens. I suggest showing the quantile distributions for Tmin and Tmax for a particular grid cell where Tmin>Tmax occurs and explain how Tmin and Tmax of the SCE period are mapped in an inconsistent way. A different way would be to construct a synthetic case with some clear assumptions that lead to occurrences of Tmin>Tmax when quantile-mapping is applied. These further explanations might be helpful to readers that are not so familiar with quantile statistics but still want to know more about the possible traps when applying quantilemapping.

AR: The third paragraph of the Results and Discussion section of the manuscript now includes the following elaboration: "…climate model errors in simulating snow would have a direct impact on DTR, with increased DTR being related to increased snow melt (Karl et al., 1993), or conversely, increased snow presence being related to a decreased DTR, especially early and late in the snow season, due largely to the large decline in Tmax when snow is present due to increased albedo (Leathers et al., 1995)." This, combined with the case study illustration above (which shows a GCM simulating a much larger DTR than observed) provides a greater explanation and illustration of what may be occurring. The processes behind this phenomenon, and more importantly how well these are represented in GCMs, is beyond the scope of this technical note.

Caption Fig. 2: April instead of Aril

AR: Thank you. That has been corrected.

Reviewer 2 (RC C2533) A. Gobiet (Referee)

Summary and General Comments The authors present an alternative approach to correct minimum and maximum temperature from GCMs with quantile mapping, in order to avoid unphysical (negative) values of the diurnal temperature range (DTR). This is accomplished by directly correcting DTR instead of deriving it from corrected Tmin and Tmax. It is demonstrated that negative DTR values occur after bias correction (BC) with quantile mapping and the authors argue that their approach avoids negative DTRs, while not degrading Tmin and Tmax too much. The study is of practical value for several applications in hydrological climate impact research and therefore suitable as a technical note in HESS. The method is clearly described, properly evaluated and the evaluation results support the conclusions.

The authors don't comment much on the characteristics of cases with negative DTR (see specific comments below). More information on such cases would be beneficial for better understanding of the issue and for further future development of bias correction methods.

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AR: As noted above, a specific case has been added for illustrative purposes. This included additional text and three added figures, which should make what we are describing much more clear.

Specific Comments P5517: You refer to Quintana Segui et al. (2010) as reference for unrealistic DTR after quantile mapping. However, Quintana Segui et al. didn't comment on DTR and comment only very generally: "... there is no physical coherence between the different corrected variables." They don't investigate the validity of this hypothesis in any respect. I regard this reference as unsuitable.

AR: We agree. This reference has been removed, as it was not as applicable to the point we were making as we had initially thought.

Figure 1: The numbers below the legend are hard to read. Please use a larger font.

AR: Figure 1 will be revised in the manuscript.

P5519: You demonstrate that after BC cases with Tmin > Tmax occur. It would be very interesting to analyze these cases in more depth. I assume that they occur on days where DTR in the GCM is very small. Probably also the resulting negative DTR values are quite small? Please give more information on the characteristics of such unphysical cases: Under what circumstances do they occur? How large is the typical error in DTR in such cases? This will help the reader to judge the severity of the problem.

AR: This is good intuition. We added an analysis at one candidate cell with many cases of Tmin>tmax after BC, and in fact, the DTR was much lower than typical when these instances occur. In the revised manuscript, the added figures and description of the case should illustrate what is happening to a much better degree.

P5519f: You demonstrate that "derived Tmin" performs much better than "derived Tmax". Any explanation for that? This basically means that BC of Tmax works better than BC of Tmin (since derived Tmin = Tmax – DTR, derived Tmax = Tmin + DTR, and DTR is the same in both cases). One could speculate, that local Tmax is better correlated to the large scale than local Tmin (night-time, frequent inversions, . . .). This could lead to a better performance of BC. The paper would gain from more information with regard to that. If possible (without speculating too much), please comment on it.

AR: This is a very good point, and the speculation appears reasonable. One of the authors, in an independent work (currently in review), had also found GCM Tmax much more amenable to bias correction than Tmin, since the biases appear much more stable with time. However, a search of the literature has not found this case made before, at least in a widespread , systematic way. For instance, Domonkos et al, 2003 “Variability of extreme temperature events in south–central Europe during the 20th century and its relationship with large-scale circulation” seems to show the opposite, that extreme cold events (admitedly not identical to daily Tmin) may be well correlated to large scale patterns, though this was for one specific region. Another based in the US, Loikith et al, 2012, Characteristics of Observed Atmospheric Circulation Patterns Associated with Temperature Extremes over North America (in press), seems to have mixed results on the topic, where both extreme warm and extreme cold events are linked to large-scale phenomena. As tempting as it is to speculate on this sort of cause, we neither have the evidence, nor do we find support in the literature to make specific claims. The revised manuscript, in the second to last paragraph of the Results and discussion section states: “That GCM simulated Tmax appears more capable of benefiting from a quantile mapping bias correction than Tmin suggests that the biases, relative to observations, exhibited for Tmax may be more systematic than those for Tmin. While a mechanism explaining this has neither been expressed in the literature, to the authors’ knowledge, nor been proposed here, the consistency with other research results (Maurer et al, 2012, manuscript in review) is encouraging as a topic for future efforts."

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 9, 5515, 2012.

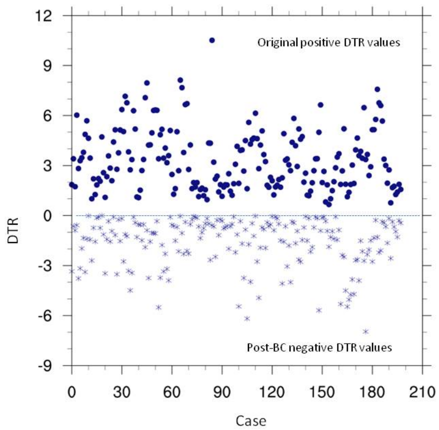

Figure 2 - Cases where Tmin>Tmax at the Grid Cell at 57N, 43E, during 1980-1989 for GCM run MRI run 3.

Fig. 1.

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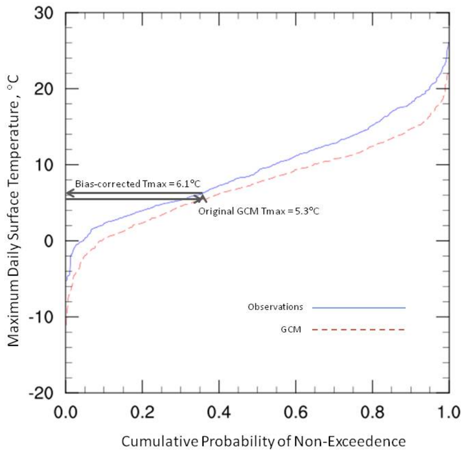

Figure 3 - CDFs for maximum daily temperature based on the period 1961-1980 for observations and MRI run3. Arrows illustrate the quantile mapping for the daily Tmax value for April 17, 1983.

Fig. 2.

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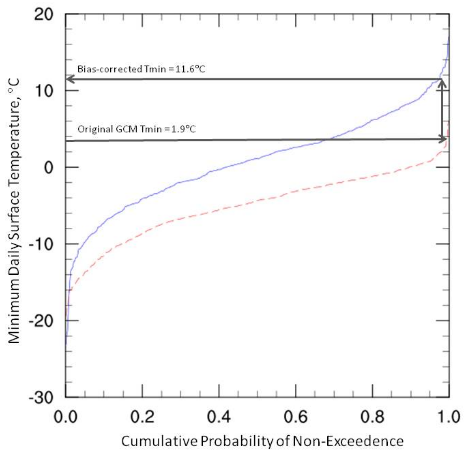

Figure 4 - Same as Figure 3, but for minimum daily temperatures.

Fig. 3.

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